Overview article
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DEVELOPMENT OF MINE-BLAST TRAUMA SEVERITY SCORE FOR LOWER EXTREMITIES IN MEN

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ABSTRACT: This study presented the results of the analysis of existing approaches to the assessment of the severity of lower extremity injuries protected with explosion-proof shoes in case of mine-explosive ammunition explosion. An increasing number of mine explosives are used in modern local wars and armed conflicts. At present, more than 110 million mines are planted and activated. Every year, nearly 10 thousand individuals are killed by explosive demolitions, and more than 20 thousand civilians sustain injuries. The necessity to clear minefields and to destroy located ammunition increases the risks of mine clearance specialists to mine-blast trauma of the lower extremities. To reduce the likelihood of severe trauma in this population, developing effective blast protective equipment, such as anti-mine boots, is necessary. The effectiveness evaluation of protective boots requires special methodology that should comprise relevant methods of mine-blast trauma severity estimation. Mine-blast trauma is a special type of surgical pathology where the injured individual has extremity avulsion or multiple injuries to extremity tissues accompanied by severe impairment of body functions. Almost all available domestic classifications of mine-explosive wounds have a pronounced clinical orientation, and foreign ones have terminologies that are not accepted in Russia and cannot be fully used for assessment purposes. The modified working classification, in the form of a rating scale, showed not only the characteristics of a given blast trauma but also the criteria of trauma severity estimation and feasibility of exposure to blast trauma. The results of the study demonstrated the potential for its use to estimate the protective features of mine clearance specialist boots when exposed to charge explosion, as well as recommendations to include this classification in documenting the science and technology that deal with the general specifications of protective equipment for specialists at the project stage.

Keywords: servicemen; anti-mine boots for specialists; contact detonation; mine-blast trauma; lower extremities; trauma severity estimation; anti-personnel mine; individual protective means; forensic medicine.

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РАЗРАБОТКА ШКАЛЫ ОЦЕНКИ ТЯЖЕСТИ МИННО-ВЗРЫВНЫХ РАНЕНИЙ ЗАЩИЩЕННЫХ НИЖНИХ КОНЕЧНОСТЕЙ ЧЕЛОВЕКА

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Резюме. Рассмотрены результаты анализа существующих подходов к оценке тяжести повреждений нижних конечностей человека, защищенных взрывозащитной обувью, при подрыве на минно-взрывном боеприпасе. Известно, что в современных локальных войнах и вооруженных конфликтах наблюдается все более широкое применение минно-взрывных боеприпасов. В настоящее время в мире установлено и находится в боевом положении свыше 110 млн мин. Ежегодно при подрывах на взрывоопасных предметах погибает около 10 тыс. человек и более 20 тыс. мирных жителей получают увечья. Необходимость проведения разминирования территории и уничтожения обнаруженных боеприпасов несут риски получения специалистами минно-взрывной травмы конечностей. Для снижения вероятности тяжелого поражения саперов требуется разработка эффективных средств защиты от взрыва, к числу которых относится защитная обувь сапера. Оценка ее защитной эффективности требует использования особого методического аппарата, который должен включать соответствующие методы оценки тяжести полученных минно-взрывных повреждений. Минно-взрывные ранения являются особым видом боевой хирургической патологии, когда у пострадавших отмечаются отрывы и множественные повреждения тканей конечностей, сопровождающиеся тяжелыми нарушениями функционального состояния организма. Выявлено, что практически все имеющиеся отечественные классификации минно-взрывных ранений имеют выраженную клиническую направленность, а зарубежные — не принятую в России терминологию и не могут быть в полной мере использованы в испытательных целях. Предложен вариант рабочей классификации в виде оценочной шкалы, не только отражающей особенности данного вида минно-взрывной травмы, но и содержащей критерии оценки тяжести и допустимости полученных минно-взрывных повреждений. Показана возможность ее применения для оценки защитных свойств обуви сапера при подрыве под ней зарядов взрывчатого вещества с рекомендацией включения данной методики в соответствующую научно-техническую документацию системы общих технических требований к средствам индивидуальной защиты сапера при ее разработке.

Ключевые слова: военнослужащие; защитная обувь сапера; контактный подрыв; минно-взрывная травма; нижние конечности; оценка тяжести повреждения; противопехотная мина; средства индивидуальной защиты; судебно-медицинская экспертиза.

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ЭКО•ВЕКТОР

Mine-explosive munitions are used increasingly in modern local wars and armed conflicts. If, at the beginning of the last century, during the Russo-Japanese war, the share of explosive injuries did not exceed 20%, then in modern armed conflicts, it accounted for at least 69% of all combat injuries [1–3].

This problem remains relevant in areas where, at the end of active hostilities, a considerable number of minefields, mined objects, unexploded ballistic projectiles, and bombs persist. At the same time, most explosive munitions do not lose their combat qualities for many decades. According to the United Nations, more than 110 million mines are currently installed and combating with the territories (in almost 60 countries). Every year, about 10,000 people die, and more than 20,000 civilians are injured in explosions of explosive objects [4–6].

All this necessitates mine clearance of the territory and destruction of discovered munitions with the involvement of specialists whose working conditions carry the risk of mine-blast trauma (MBT) to their limbs. The development of personal protective equipment against explosions is required to reduce the probability of a severe sapper injury, which includes sapper safety footwear (SSF). The evaluation of its protective efficiency requires using a special methodological apparatus, including appropriate methods for assessing the severity of mine-explosive damage (MED), which is only possible with the active participation of medical professionals [7, 8].

Mine-explosive wounds (MEW) are considered a special type of combat surgical pathology. Regardless of the mechanism of detonation, all victims with the severe contusion-commotion syndrome and blood loss have avulsions or multiple damages to limb tissues, accompanied by severe impairment of the functional state of the body. It is the severity of primary injuries and the course of traumatic disease in this group of wounded patients, accompanied by a large number of infectious complications and a high degree of disability, which require diversified studies to develop an effective system of pathogenetically substantiated therapeutic and preventive measures [9–11].

Several Russian authors propose dividing the whole variety of MBT into two main clinical variants: MEW, which arises mainly as a result of the contact mechanism of detonation in unshielded (unprotected) personnel, and MED, characterized, as a rule, by an indirect (non-contact) mechanism of exposure to explosion factors (usually in protected personnel). At the same time, MEW is mainly characterized by a combination of explosive destruction and avulsion of limbs with a predominantly closed craniocerebral injury, closed injuries and/or wounds, including penetrating ones, of the chest, abdomen, and pelvis. MED is characterized by closed (mainly) and open injuries of the musculoskeletal system (multiple comminuted fractures, dislocations, bruises) and internal organs, combined with a general concussion-commotion syndrome [12, 13].

In practice, it is not always possible to distinguish MEW and MED. If the efficiency of the protective equipment and the power of the explosive device do not correspond to each other, the clinical manifestations of MEW will often prevail. In this regard, for military field surgeons, in our opinion, the therapeutic-tactical classification proposed by E.K. Gumanenko [14] is more suitable. It correlates with the general classification of combat trauma and determines the surgical approach. In this classification, all injuries that occur in the wounded from exposure to explosion factors are proposed to be divided into three groups: namely, MEW that occurs in the zone of direct damage and is necessarily accompanied by explosive destruction of tissues and avulsion of limb segments; explosive injuries (EI) arising from the action of all explosion factors in the absence of direct contact with an explosive device, taking into account the propelling effect of the explosion, the impact of surrounding objects and armor damage; shrapnel wounds outside the affected area by other factors of explosion.

In the range of the Russian methods for assessing the severity of a combat gunshot injury, the scale for assessing the severity of gunshot injuries, "Military Field Surgery — Injuries (gunshot wounds) — MFS-I (GW)," developed by specialists from the Department of Military Field Surgery of the S.M. Kirov Military Medical Academy, based on the analysis of the experience of providing surgical care to the wounded in local wars and armed conflicts of recent decades [15], is most widely used by military doctors.

The severity of all cumulative injuries in a wounded person is assessed by assigning an appropriate score to each injury identified. At the same time, for ease of use, the authors divided possible injuries by body regions, which are presented in separate Tables. The proposed assessment of the severity of gunshot injuries to the limbs is presented in Table 1.

The scores obtained are summarized with a subsequent gradation of the severity of the injury into mild (0.05–0.4), moderate (0.5–0.9), severe (1–12), and extremely severe (> 12) with a mortality rate of 0%, < 1%, 1–50%, and > 50%, respectively.

It should be noted that this scale is intended for the battlefield surgeon to make a medical and evacuation decision regarding the wounded with a gunshot wound. Accordingly, it does not fully consider all the local and general aspects of the MBT.

Based on the experience of medical support for the Soviet contingent in Afghanistan, V.M. Shapovalov [16] proposed his classification of explosive wounds and injuries. According to this classification, MEW and MBT are particular types of blast wounds and injuries, divided by the nature of the injury, concomitant tissue damage, the presence of associated injuries, and the nature, type, and localization of fractures and articular injuries. A shaped charge, a grenade, and a primer are separately identified as a source of explosive wounds. In addition to describing the morphological manifestations of EI

of the extremities, this classification included the possibility of simultaneous assessment of emerging functional disorders in the form of determining the degree of blood loss and the severity of the developing shock.

In addition, the classification considered all kinds of injuries received by patients as a result of direct and indirect exposure to explosion factors, which enabled making a detailed clinical diagnosis. However, in addition to the possibility of forming a detailed morpho-functional diagnosis, this model cannot be used to determine the specifics of the identified damage and does not contain a categorization algorithm, which, in turn, does not allow the full application of this classification when assessing the quality of explosion-proof equipment (in particular, SSF) [17].

Undoubtedly, the severity of EI can also be determined using the appropriate damage scales, presented as a conditional quantitative (numerical) characteristic (code) of the type and severity of each specific injury.

The best-known scale of this type, used worldwide, is the Abbreviated Injury Scale (AIS) proposed by the American Medical Association [18].

In the AIS system, each injury is assessed by nature and severity. At the same time, the AIS scale only assesses the severity of isolated injuries since the summation of severity codes is unacceptable. The identified injuries are ranked on a scale from 1 to 6 points (Table 2).

The AIS scale has several significant disadvantages, the main of which is its subjectivity in assessing the severity of injuries, leading to a mechanical combining of injuries of various localizations based on arbitrary criteria, as well as the possibility of assessing only isolated injuries. At the same time, MEW is characterized by multiple and combined injuries [19].

Another example of the implementation of the clinical approach is the Bastian classification of explosive lower limb injury proposed in 2014 and developed by a group of specialists from the Camp Bastion field hospital deployed by the British contingent in Afghanistan from 2006 to 2014 [20]. This classification involves the division of the wounded into five classes, depending on the level of injury to the lower extremities:

– class I—only the foot is damaged (destroyed);

Table 1. Trauma severity score by the rating scale "Military field surgery injuries (gunshot wounds): the extremities"
Таблица 1. Оценка тяжести повреждений по шкале «ВПХ-П (ОР) — конечности»

Nature and localization of injuries	Severity of injuries, score
Circumscribed wounds of the soft tissues of the extremities	0.05
Non-penetrating wounds of the major joints	0.1
Circumscribed wounds of the soft tissues of the foot	0.2
Marginal and perforating fractures of the long bones	0.2
Penetrating wounds of the small joints	0.2
Extensive soft tissue wounds on the extremities	0.6
Circumscribed wounds of the soft tissues and the bones of the foot	0.8
Penetrating wounds of the major joints	1
Lower leg fracture	2
Extensive wounds of the soft tissues and the bones of the foot	2
Damage to the major nerves	2
Hip fracture avulsion	3
Hip fracture	3
Damage to the main vessels of the limbs	4
Lower leg avulsion	4
Thigh avulsion	10

Table 2. AIS-abbreviated trauma score
Таблица 2. Сокращенная шкала повреждений AIS

Score	Severity of damage
1	Mild
2	Medium
3	Severe, not life-threatening
4	Severe, not life-threatening, with the probability of survival
5	Life-threatening, with improbable survival
6	Fatal, with a lethal outcome within 24 hours

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- class II—destruction above the foot with the possibility of applying a tourniquet below the knee;
- class III—destruction above the knee with the possibility of applying a tourniquet to the thigh;
- class IV—destruction above the knee, but with the impossibility of applying a tourniquet to the thigh;
- class V—explosive injury of the gluteal region.

In addition, depending on the nature of the concomitant injury above the thigh level, the wounded are assigned four letter indexes (A—penetrating wound of the abdomen; B—damage to the genitals and perineum; C—impairment of the integrity of the pelvic ring; D—the trauma of the upper limb).

This classification also has clinical and approach significance. Each wounded patient is assigned a particular class of damage, which determines the level of assistance and the nature of medical and evacuation measures. Surgical care can be provided in a military district hospital with a class II explosive injury. In contrast, with a class III injury, the participation of a vascular surgeon is already required, with the need to evacuate the wounded to a specialized hospital. The clarity and simplicity of assessing the severity of patients in this classification are instrumental in the case of a mass admission of the wounded [21].

In general, the classifications presented above cannot be fully used to evaluate protective footwear, as they preclude assessing the admissibility of a particular impact.

Currently, when testing protective footwear in the North Atlantic Alliance countries, the Mine Trauma Score (MTS, Table 3) [22] is successfully used.

As a limit characterizing the required level of protection of the lower limb of a serviceman with special footwear, the MTS value up to 1b inclusive is taken when such injuries of the lower limb that do not lead to the foot amputation are allowed ("no major surgical intervention is required" or "surgical intervention is required, the limb can be saved") [23].

We [24] proposed our version of the working classification in the form of an MBT rating scale for the lower extremities of a person for assessing samples of explosion-proof footwear with additional justification for the severity of damage in the form of a predicted percentage of the permanent loss of the general ability to work (Table 4).

In the rating scale presented, open uncontaminated injuries imply open fractures of the foot bones while maintaining the integrity of the shoe from the inside. In contrast, open contaminated injuries are open fractures of the bones of the foot with a violation of the shoe integrity from the inside. In the presence of simultaneous three or more signs of the damage presented the MBT severity increases by a stage.

The sequence of work with this scale involves comparing all the damage to the protected lower limb of the wounded (after the explosion) with the injuries indicated in the relevant sections of the Table and determining their severity in points. Each score corresponds not only to its morphological criteria for damage but also to the necessary medical care specifying the possible outcome regarding the level of necessary amputation and the expected degree of loss of the general ability to work. For each score, there is a gradation according to the presence or absence of a violation of the integrity of the footwear protective structures. The resulting score indicates the admissibility of the identified damage, which is the criterion for the efficiency of the protective characteristics of the tested sample of explosion-proof footwear.

Indeed, from the standpoint of maintaining human health, the absence of injuries in explosions in protective shoes is optimal. However, the question arises of the achievability of this result when using the available design solutions, technical means, and materials used. An equally important issue is the ergonomic properties of footwear. Having good protective characteristics, footwear may be unsuitable for wearing and performing combat training tasks typical of the professional military activity of a sapper.

Normalization of exposure, concerning the assessment of footwear's protective properties, is a complex, multifactorial sociobiological problem. The basic principles of normalization are undoubtedly general. However, for hygienic regulation,

Table 3. Mine-blast trauma score accepted in North Atlantic Treaty Organization
Таблица 3. Шкала минно-взрывной травмы, принятая в Североатлантическом альянсе

Severity	Type of injury	Surgical approach
0	Minimal	No major surgery required
1	Closed	Surgery is required, and the limb can be saved
1a	Open uncontaminated	
1b	Open contaminated	
2	Closed	Below-the-knee amputation is required
2a	Open uncontaminated	
2b	Open contaminated	
3	Open contaminated	Amputation at the level of the lower leg or thigh is required
4	Open contaminated	Amputation at thigh level is required

Таблица 4. Оценочная шкала минно-взрывной травмы нижних конечностей человека для оценки образцов взрывозащитной обуви
Table 4. Mine-blast trauma score for lower extremities used to estimate samples of anti-mine boots

MBT severity		Nature of injury	Signs of injuries	Medical care required	Prognosis of loss of general ability to work, %
0		Minor	– bruises of the soft tissues of the foot and lower leg; – abrasions, ecchymosis, and circumscribed hemorrhages in the soft tissues of the foot	Conservative treatment is indicated	less than 5
1	1A	Minimal	– damage to the ligaments of the foot and the ankle joint; – fractures of the bones of the tarsus, 1–2 metatarsal bones, and phalanges of the toes; – fractures of the ankle joint without the displacement of fragments	Conservative treatment is possible	5–9
	1B		– fractures of the calcaneus, the talus without the displacement of fragments; – fracture of the distal metaepiphysis of the tibia without the displacement of fragments.		10–19
2	2A	Closed	– comminuted fractures or fracture-dislocations of the bones of the tarsus and the metatarsus; – fractures of the calcaneus and talus bones with the displacement of fragments; – fractures of the ankle joint with the displacement of fragments; – fractures of the bones of the lower leg with the displacement of fragments	Foot-sparing surgery is required	20–29
	2Б	Open uncontaminated	– the destruction of the foot at the level of the metatarsus, the tarsus; – defect of integumentary tissues up to 30% of the foot surface; – comminuted fractures or fracture-dislocations of the bones of the tarsus and the metatarsus; – fractures of the calcaneus and talus bones with the displacement of fragments; – fractures of the ankle joint with the displacement of fragments; – fractures of the lower leg bones with the displacement of fragments		30–39
	2C	Open contaminated	– the same as 2B in case of the shoe integrity violation from inside		
3	3A	Closed	– multiple multi-comminuted fractures with the destruction of the foot bones; – injury/thrombosis of the posterior tibial, anterior tibial, and fibular arteries	Amputation of the foot or lower third of the leg is required	40–49
	3B	Open uncontaminated	– the destruction of the foot at the ankle joint level; – defect of integumentary tissues up to 50% of the foot surface		
	3C	Open contaminated	– the same as 3B in case of the shoe integrity violation from inside		
4		Open contaminated	– defect of more than 50% of the soft tissues of the foot; – the destruction of the lower leg to the level of the distal metaepiphysis of the tibia; – damage to the popliteal artery	Amputation at the level of the upper third of the lower leg is required	50–59
5		Open contaminated	– the destruction of the lower leg at the upper third level; – the destruction of the knee joint; – damage to the femoral artery	Amputation at the level of the lower third of the thigh is required	60–65

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this is primarily the principle of guarantee, which guarantees maintaining health (in the broadest sense of the word), working capacity, and, in some cases, human life [25].

Already this definition comprises another principle of normalization, namely the principle of differentiation, which provides the development of not only the optimal and maximum permissible values of the acting factor but also the maximum permissible and maximum tolerable levels. The rationing criterion is sometimes not health but working capacity (combat capability) and even survivability [26].

Concerning rationing of mine-explosive impact when testing protective footwear, in our opinion, the following two levels of rationing are appropriate:

- the maximum (or utmost) allowable;
- the maximum (or utmost) tolerable.

At the maximum allowable level of exposure, some decrease in working capacity and temporary deterioration of health is allowed. This is the level of emergencies and wartime. The maximum tolerable level of survival allows for a decline in working capacity, incapacitation, and deterioration in health. In general, it is intended for use in exceptional wartime situations.

In addition, during explosions in anti-personnel mines, the maximum permissible level should preserve the working capacity (combat capability) of the user of protective footwear, allowing only short-term incapacitation from the working cycle with minimal damage to health. These conditions will be met in cases where the user will experience damage in the form of abrasions, bruises, and minor superficial wounds that do not entail health disorders or permanent loss of general ability to work and are not regarded as "harm to health."

The indicated level of regulation can be used when setting requirements for protective footwear for military specialists needing enhanced countermining protection.

The maximum tolerable level is the level of survival that ensures the preservation of the user's life. For this level, the absence of serious harm to health, one of the signs of life-threatening injuries or causally associated life-threatening conditions, must be ensured.

The well-established forensic practice indicates that the medical criteria for qualifying signs concerning severe harm to health in injuries of the lower extremities are the following:

- harm to health, hazardous to human life, which by its nature directly poses a threat to life, as well as harm to health that caused the development of a life-threatening condition, namely "acute, profuse, or massive blood loss;"
- loss of any organ or loss of its functions by an organ, in particular: "loss of an arm or leg, i.e., their avulsion from the body, or permanent loss of their functions ...; loss of a hand or foot is equivalent to the loss of an arm or leg";
- "significant permanent loss of general ability to work by at least one-third (persistent loss of general ability to work over 30%)."

Severe harm to health, causing a significant permanent loss of general ability to work by at least one-third, that is, more than 30%, regardless of the outcome and provision (non-provision) of medical care, also includes an open or closed fracture of the ankles of both tibia bones in combination with a fracture of the articular surface of the tibia and rupture of the distal tibiofibular syndesmosis with subluxation and dislocation of the foot [27, 28].

Therefore, for the maximum tolerable level of mine-explosive impact, only harm to health, estimated at no more than moderate severity, which implies no danger to life, allowed short-term or long-term health disorder (temporary disability lasting up to or more than 21 days, respectively) or persistent loss of general ability to work up to 10% or from 10% to 30% inclusive, can be acceptable. Such patients will either not need surgical care during the stages of medical evacuation or will need it to save the limb.

Until additional experimental studies are conducted, it is challenging to estimate the acceptability of forensic medical criteria unambiguously for assessing the severity of harm to human health for testing protective footwear. Such criteria may not be fully suitable for assessing mine-EI.

In general, the requirements for anti-mine footwear can comprise two regulatory levels: the level of maintaining the working capacity (maximum allowable) and the level of survival (maximum tolerable).

As already noted, for the maximum permissible level of exposure, injuries in the form of abrasions, bruises, and minor superficial wounds can be permissible, which do not entail a short-term health disorder or an insignificant permanent loss of general ability to work. For the maximum tolerable level, injuries up to 2A points inclusive, according to the proposed classification (Table 4), can be permissible, including those requiring surgical intervention:

- comminuted fractures or fracture-dislocations of the bones of the tarsus and the metatarsus;
- fractures of the calcaneus and talus bones with the displacement of fragments;
- fractures of the ankle joint with the displacement of fragments;
- fractures of the bones of the lower leg with the displacement of fragments.

Despite the relatively favorable probable outcome of similar open-type injuries (with the skin integrity damage), they apparently should not be allowed when evaluating and monitoring the protective properties of footwear at the test stages since any open-type injuries create prerequisites for developing complications of MED in the near or the distant future.

Thus, damage to the lower limbs protected with explosion-proof footwear that occur during contact detonation can be classified as a different type of "beyond-barrier" MEW as mine-explosive wounds in the SSF, characterized by almost complete leveling of all factors of a close explosion, especially its brisance action, under

the condition of sufficient efficiency of protective properties of footwear and preservation of its integrity. In this case, the wounded person may experience various "impact" (mostly closed) injuries in the form of abrasions, bruises of soft tissues, damage to the ligamentous apparatus, and fractures of the bones of the foot and lower leg of varying intensity. When the structure of protective footwear is destroyed, the lower limb may be exposed to all factors of the explosion, although weakened to a certain extent. In this case, damage typical of the classic contact MEW (mainly open) can be noted, accompanied in extreme cases by severe tissue damage and avulsion of the lower limb segments.

It is advisable to use the proposed version of the rating scale to conduct biomedical tests of the protective properties of the sapper's footwear since it considers not only the morphology of injuries and treatment approach but also their possible consequences for the health of the victim regarding hazard to life and permanent loss of general ability to work. From the medical point of view, as a criterion for sufficient protective efficiency of footwear, it is most advisable to allow only minimal damage to the lower limb, no higher than 1A severity, amenable to conservative treatment, not life-threatening and leading to a minimum degree of permanent loss of general ability to work (up to 10%). However, at this stage of technical development, the achievement of such a result is most probably highly doubtful without deterioration in the ergonomic properties of footwear in the form of weighting and increasing the height of the sole, which may not allow the specialists of the sapper units to perform the tasks of demining the area properly. Therefore, the permissible level of certain MEW remains debatable from the point of view of maintaining the optimal balance between the ergonomic and protective properties of the created samples of explosion-proof footwear. Moreover, the proposed classification should not be considered final and can be finalized by accumulating relevant experimental, clinical, and expert experience.

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